



# Grain Particle Size in Image Analysis

The development project of mobile forest soil analyzer  
(Final Version)

Motoki Saito

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## ABSTRACT

Tampereen ammattikorkeakoulu  
Tampere University of Applied Sciences  
The Degree Programme of Energy and Environmental Engineering

Motoki Saito:  
Grain Particle Size in Image Analysis  
The Development Project of Mobile Forest Soil Analyzer

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This thesis explores the image analysis of forest soil, supported by LUKE and DEMOLA. Heavy forestry vehicles have been facing mobility issues in weak soil. Ruts, which are created by those vehicles in the wet condition, contain a certain amount of clay, fine fraction, and moisture. Thesis aims at designing affordable and simple processes of soil image analysis to determine clay contents and gain particle distribution of clay, silt and sand in soil samples. Grain images are captured by a smartphone camera, and the result is compared with images from a microscope in *imageJ* since a microscope is designed for capturing microscopic images.

Hence, three research questions are created: Q1. Can grain particle such as clay, silt and sand be identified by use of the images? Q2. What standardized process can be gone through the image analysis of grain particle? Q3. Can we find out the minimum specification of smartphone camera to capture grain particle? By answering those, the possibility of image analysis in soil science is recognized.

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Key words: grain particle, image analysis, forest soil

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**GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)**

LUKE	Luonnonvarakeskus (Natural Resources Institute Finland).
EFFORTE	The research and innovation project providing efficient forestry for sustainable and cost-competitive bio-based industry (2016-2019).
TAMK	Tampere University of Applied Sciences
NIH	The National Institutes of Health in the United States
NASA	National Aeronautics and Space Administration
TUT	Tampere University of Technology
MER	The Mars Exploration Rover mission
MSL	The Mars Science Laboratory
CPU	Central Processing Unit
UX	User Experience
API	Application Program Interface

## 1 INTRODUCTION

Can traditional sieving method be replaced by the use of digital image analysis in sorting grain? This question was thrown by Luonnonvarakeskus (LUKE) at Demola project meeting in autumn 2017. When I joined the project with other four members, I was interested in the digitalization of modern forestry operation. As the variety of industries from security (face recognition system) to pharmaceutical (automating microscopic analysis) and agriculture (precision agriculture) utilize digital image analysis, forestry could also realize the use of image analysis to reduce and optimize work processes.

Forestry scientists focus on studying the relationship between types of soil and the effective forestry operations of heavy vehicles such as harvester and forwarder in the EU funded research project, which is called EFFORTE. When the soil strength becomes weak in wet season, ruts are created by vehicles. The deeper the rut becomes, the more the heavy vehicles affect mobility. Clay content in soil is one of key elements to determine the soil strength, which is called soil bearing capacity. Bearing capacity of clay content higher than 10% and that of both silt and clay higher than 30% is highly influenced by the moisture content in the soil (LUKE 2019, 7). The risk of disturbance of heavy vehicles' operations in the wet season, is therefore reduced if the clay contents are known in advance. This can be done by installing a camera and application in the forestry vehicle or carrying a smartphone while forestry owner decides harvesting route.

According to the Climate-ADAPT web site, which is supported by the EU and the European Environmental Agency (EEA), the climate change has already been causing the increase of precipitation and river flows in Boreal region. It is also differently affecting all regions in Europe. The decrease of snowfall and increase of rainfall continues as trend (Climate ADAPT, 2017).

The smartphone-based soil analysis system will be useful not only in forestry, but also in mining, agriculture, and construction sectors if the system is more convenient and less expensive than conventional sieving analysis and analysis in

laboratory. Moreover, the image analysis system will be useful in the developing countries where facilities/laboratories do not exist nearby.

The digital image analysis is commonly used in NASA's Mars Exploration Rover (MER) mission to determine grain size and shape because human cannot make an access to the Martian soil. Martian soil was visible in thousands of digital pictures, which were sent by the rovers, Opportunity and Spirit. The NASA can analyze Martian soil from images in space. Then why soil on the earth could not be analyzed in the same way?

The camera is one of the key issues. The rovers on Mars were equipped high-resolution camera, which has 1024 x 1024 pixels in size with 31  $\mu\text{m}$  at best focus. From the digital images, the shapes and structures of the Martian soil were estimated through algorithm (Kozakiewicz, 2018). According to Kozakiewicz's research in MER, Fuji FinePix S2995 camera, which is available in market, was used for image data comparison. In particular, the digital camera, which costed around 102 euro in 2017 (hinta.fi 2017) and was not specially designed, was used in the experiment of image analysis algorithm in NASA. To capture a soil image does not require an expensive camera.

The algorithm is another important issue. *ImageJ*, which is one of well-known image analysis algorithms, was used in MER and this project. Algorithm in *imageJ* is a series of process such as smooth, sharpen, find edges, and find maxima to determine grain size distribution in the image. The result can be displayed quicker in the software than done by the sieving method. Moreover, the method of soil image analysis can be more sustainable and efficient than conventional sieving method to determine grain size distribution (Ohm, Sahadewa, Hryciw, Zekkos, & Brant 2013, 1647). Specifically, image analysis does not consume water and uses very little electricity.

*ImageJ* is open source software, developed by Wayne Rasband of National Institute of Mental Health, USA. It can read most common image formats such as *tiff*, *gif*, *jpeg*, *bmp*, and raw data format. It can also calculate area, scale images, and calibrate real world dimensional measurement in units such as mm and  $\mu\text{m}$  (NIH, 2019).

This thesis explores the morphological parameters of forest soil through digital images as NASA did for the images of the Martian soil. The project aims at designing affordable and portable system of soil image analysis to determine clay contents and gain particle distribution of clay, silt and sand in soil samples. Grain images are captured by a smartphone camera, and the result is compared with images from a microscope in *imageJ* since a microscope is designed for capturing microscopic images.

In addition, a smartphone application (Mobile app) will also be designed to support the optimum image analysis process. Confirming the image analysis has more priority than software development. Waterfall development model was conducted so that it had four phases. However only the first and second phase were conducted in this project, because software should be connected with image analysis and the design and image analysis must be approved by LUKE first, before continuing on to the third and final phase.

## 2 THE AIM OF THIS WORK

In this thesis, my aim is to distinguish the types of soil by the different particle sizes among sand ( $>63\text{ }\mu\text{m}$  and  $\leq 2000\text{ }\mu\text{m}$ ), silt ( $> 3.9\text{ }\mu\text{m}$  and  $\leq 63\text{ }\mu\text{m}$ ), and clay ( $\leq 3.9\text{ }\mu\text{m}$ ), which were classified by a pioneer sedimentologist Wentworth through the digital image analysis (Wentworth 1922, 381).

I will use images from a smartphone camera with external macro lens, and they were justified by images from a microscope, which specializes microscopic images. A particle distribution in each image was calculated by *imageJ* software, which is well-known in the digital image analysis. Finally, the soil content of sand, silt, and clay in each sample was determined by the Wentworth's soil classification.

Analyzing digital images is widespread in various industries such as face recognition in security industry, and quality control in manufacturing industry. In forestry, *Trestima Oy* developed forest inventory system, which utilizes forest pictures with the smartphone (*Trestima Oy*, 2019). Then, the question arose whether the grade of soil could be identified in the image although it is extremely small.

My main theory is how the digital image technology can be applied to identifying the grade of soil. At present, the identification work has to be done in a laboratory if the detail particle distribution needs to be known. The Martian sand grain was identified through the image in NASA (Kozakiewicz, 2018), therefore, the forest soil on the earth can be done in the same way.

If the identification of grain particle distribution works through digital image, varied benefits can be thought of. The primary benefit is saving time and cost for the soil analysis. The benefit will go to forestry, especially forest workers who drive heavy forestry vehicles. Expectedly long-lasting wet season affects harvesting. The mobility of forestry vehicles is limited and disturbed in the wet season because clay mineral holds more water than other soil types. It makes the ground extremely soft and muddy in rain. Heavy forestry vehicles create ruts and get stuck in mire. Logging operations are affected, for example.



Therefore, the European Union funded forestry research and innovation project (EFFORTE) from 2016 to 2019. It supported the investigation of new technology, which would improve forestry processes and operations. LUKE led the project in Finland. By deepening the knowledge of soil mechanics, the mobility of forest vehicles can be analyzed in advance (LUKE, 2017). The issue arouse interest in European forestry as well as other countries.

Thus, explaining the grade of soil in digital images benefits forestry. Utilizing image analysis is a modern technological trend, and the benefit will go beyond forestry.

## **2.1 Three Research Questions**

Preparing narrow scope and research questions are essential, so as to conduct the research project. The following three questions were prepared:

Q1. Can grain particle such as clay, silt and sand be identified by use of the images?

Q2. What standardized processes can be gone through the image analysis of grain particle?

Q3. Can we find out the minimum specification of smartphone camera to capture grain particle?

The first question (Q1) is the basis for this research. Three different grains are identified from the help of image analysis. The second question (Q2) is to find out the individual processes of image analysis. Accordingly, the processes will guarantee the repeatability of result, and the result will be even better by use of advanced equipment. The last question (Q3) is to identify the specification/requirement of smartphone camera when a grain image is captured.

### 3 METHODOLOGY

#### 3.1 Background

To identify the soil type in images is important to focus on grain particle size. The particle size (grain size) in sedimentology is commonly measured by the use of sieving method, and it identifies the types of soil. However, the standard of clay's and silt's content in each sample is provided by LUKE, hence, it is called the traditional approach. This project challenged the image analysis of grain particle size, which is the new quick-and-cheap approach, against the traditional approach.

The use of two different images were proposed to acquire soil particle distribution to justify the particle size in the soil samples. The particle size of clay is smaller than  $3.9\ \mu\text{m}$ , that of silt is between  $3.9\ \mu\text{m}$  and  $63\ \mu\text{m}$ , and that of sand is bigger than  $63\ \mu\text{m}$  (Wentworth 1922, 381) (Table 1). A principal approach was to use a smartphone camera with external macro lens. This method was called quick-and-cheap approach. LUKE encouraged to test this new method. Therefore, alternative method was to justify the particle size from smartphone images by use of more trustworthy approach. For that purpose, soil images from a microscope were selected. A microscope excelled in observing microscopic images. The result from microscope images was a good counterpart of mobile camera images.

TABLE 1. Simplified Wentworth's Soil Classification (Wentworth 1922, 381).

Type	Particle Size ( $\mu\text{m}$ )
Sand	$63 < x \leq 2000$
Silt	$3.9 < x \leq 63$
Clay	$x \leq 3.9$

Here were the main processes in the project (Figure 1). There were three main phases, which were preparing soil samples, capturing images with smartphone camera and microscope, and analyzing images. Utilizing common and simplified processes were arranged in the most of flows except capturing images with two different devices in order to fairly compare results. The processes in the phase II

and phase III are designed to a mobile app. From the following sections, the details of those processes were explained.

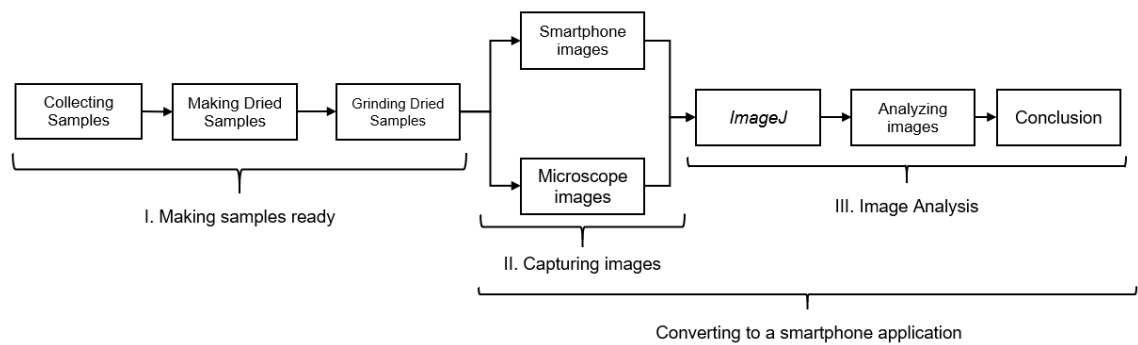


FIGURE 1. Image Analysis Process (Saito, 2019).

After the project period and resources were fixed, the waterfall software development model was conducted. The waterfall model has four phases: research, design, implementation, and testing and deployment (FIGURE 2). The use of the waterfall has a great advantage over the agile model when the project time and budget are fixed. Moreover, the phases must be completed one at a time before moving to the next phase (Hoffer, George & Valacich, 42). Therefore, the progress is easily presented. In our case of mobile app design, the waterfall model was used.



FIGURE 2. Waterfall model (Saito, 2020).

In the project, the first two phases, Research and Design, were conducted in the mobile app development (Figure 3). In the research phase, system requirement was collected. In the design phase, UX design was created. Furthermore, in December, the result was presented, and the development of the app could be conducted after the following January, but the development schedule was unconfirmed.

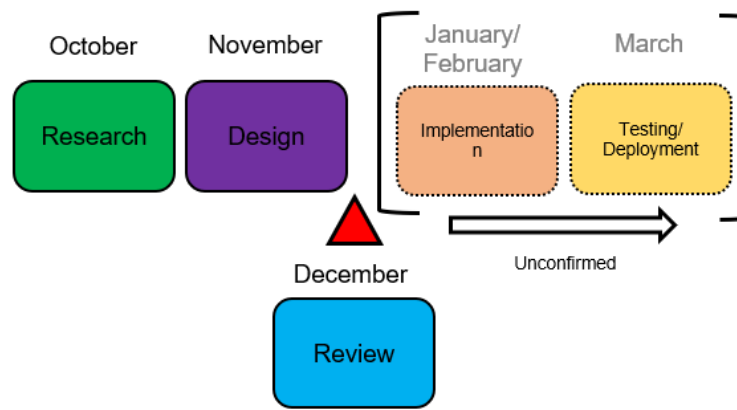


FIGURE 3. Estimated Software Development Schedule (Saito, 2020).

### 3.2 The Flow of Mobile App

A mobile app can help users by automating and reducing the processes and organizing information. In the image analysis process (Figure 1), capturing images and analyzing images will be converted into the application.

The Mobile App was designed with the following five requirements:

1. Ability to capture soil images.
2. Ability to analyze soil images.
3. Ability to view analyzed result and history data.
4. Having an easy and simple system operation flow.
5. Having data securities.

The first three requirements encouraged us to use a smartphone. According to Tilastokeskus, about 77 % of population held a smartphone in Finland in 2017 (Tilastokeskus, 2020). Hence, designing a mobile app became a solution for developing a mobile forest soil analyzer. Forthly, image analysis process is very simple, and it suits a mobile app. Fifthly, in addition to the flow of image analysis process (Figure 1), login screen was inserted for the data securities (Figure 2).

User experience (*UX*) design was used for demonstrating the usability of mobile app to users. *UX* design is fast to create from the concept and user requirements for the evaluation purposes, and it provides the similar and meaningful experience that the actual application gives to the users. *UX* design was created by

using *Mockplus*, which is well-known freeware in this field (<https://www.mock-plus.com/>).

The following system concept map was visualized from the image analysis process and the five concepts (Figure 4) based on the UX Design Mind Map (Appendix 2). Three major functions were considered for data security, adding the new data, and checking analyzed result and history. In the data security function, login function, which requires user ID and password, and administer function, which manages users. In the new data function, sample information such as location, date, and image, is managed. In the result and history function, viewing analyzed result (fail or success) and past information are managed. In this system design, the result and history data are in the cloud, but not in the local smartphone.

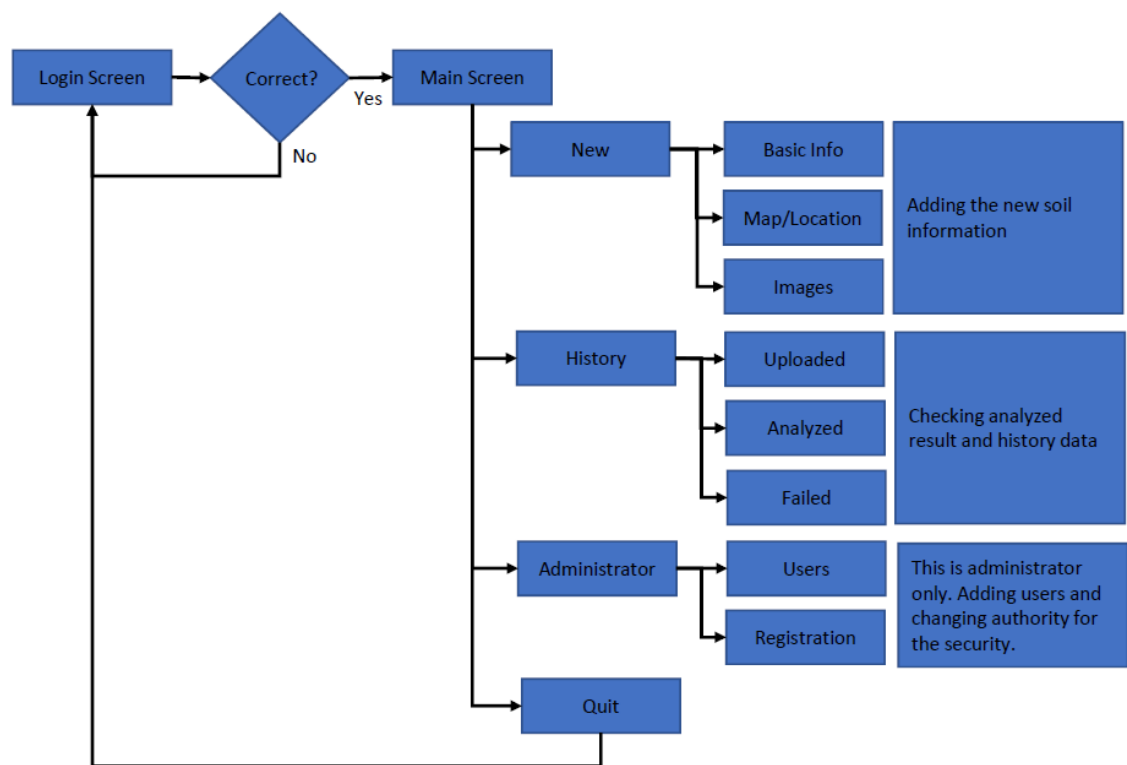


FIGURE 4. System Concept Map (Saito, 2020).

As the image analysis function requires huge space and faster *CPU*, the function had better locate in the cloud such as *Google cloud* (<https://cloud.google.com/products/ai/>), but not in the local smartphone or computer. As a result, images and analyzed results could be shared with multiple users (Figure 5). In addition, the more images are analyzed, the more accurate

the result becomes in the machine learning when all images should be stored in the same space such as Google cloud. In this reason, the use of cloud is supported in this app.

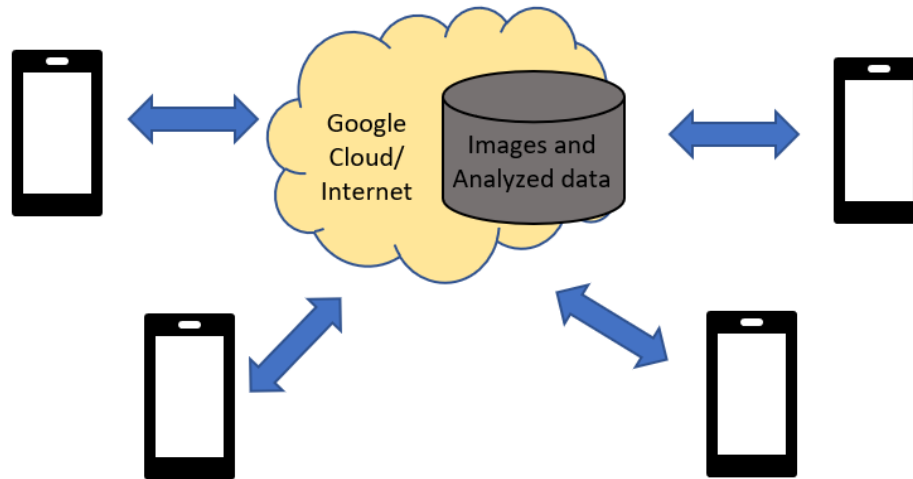


FIGURE 5. Ideal System Image (Saito, 2020).

However, the image analysis process was separately analyzed from mobile app as the project primarily targeted to confirm whether or not the soil image analysis worked. The evaluation worked faster in this way. The evaluation of mobile app design and image analysis were separately conducted (Figure 6).



FIGURE 6. Designed Unit Test (Saito, 2020).

### 3.3 Making Soil Samples Ready

Nine soil samples were provided by LUKE (Picture 1).



PICTURE 1. Soil Samples (Saito 2017).

Each fresh soil sample was numbered from 1 to 9, and the types of soil, expected clay contents and fine fraction (silt and clay) were presented by LUKE (Table 2 & Appendix 1). For example, the sample 1 was named as clay, expected clay content was more than 30 %, and the content of fine fraction (silt and clay) was more than 50 %. The sample 2 was named as silt clay, expected clay content was between 10 % and 30 %, and the content of fine fraction was between 20 % and 50 %. The sample 3 was called silt clay/sandy clay, expected clay content was between 10 % and 30 %, and the content of fine fraction was between 20 % and 50 %. The sample 4 was called low-organic clay, expected clay content was more than 30 %, and the content of fine fraction was more than 50 %. The sample 6 was called coarse silt, expected clay content was between 10 % and 30 %, and the content of fine fraction was between 20 % and 50 %. The sample 7 and 8 were called fine sand, expected clay content was less than 10 %, and the content of fine fraction was less than 20 %. The sample 9 was moraine/till, expected clay content was 0 %, and the content of fine fraction was 0 %.

TABLE 2. Expected Clay Content and Fine Fraction by Soil Samples (LUKE, 2017).

No	Sample	Expected clay content	Fine Fraction (Clay + Silt) < 0.063 mm
1	Clay	> 30 %	> 50 %
2	Silt clay (Fine silt)	10 % < x < 30 %	20 % < x < 50 %
3	Silt clay (Coarse silt)/ Sandy clay (Fine sand)	10 % < x < 30 %	20 % < x < 50 %
4	Low-organic clay	> 30 %	> 50 %
5	Fine silt	10 % < x < 30 %	20 % < x < 50 %
6	Coarse silt	10 % < x < 30 %	20 % < x < 50 %
7	Fine sand	< 10%	< 20 %
8	Fine sand	< 10%	< 20 %
9	Moraine / till	0	0

The method of drying samples was considered to be an important issue, and the idea was to dry samples on site. Drying them outside would be a part of actual operation flow; however, the project was focused on capturing images and image analysis. The drying tool was not invented. As those samples contained moisture, a few scoops of every samples were dried on the newspapers in the balcony for a few days, and each dried sample was put in the individual plastic bags. Later, those were grinded in a mortar at TAMK laboratory.

### 3.4 Capturing Images

#### 3.4.1 With Smartphone

A personal smartphone (Xiaomi RED Mi4: 13 MP) was used in the experiment. An external macro lens (Black Eye Macro 20X) was purchased (Picture 2), and it was attached to the smartphone's main camera.

The smartphone was owned by one of the project members. The specification of smartphone can be used as evaluation of hardware in the discussion.

TABLE 3. The Specification of Camera.



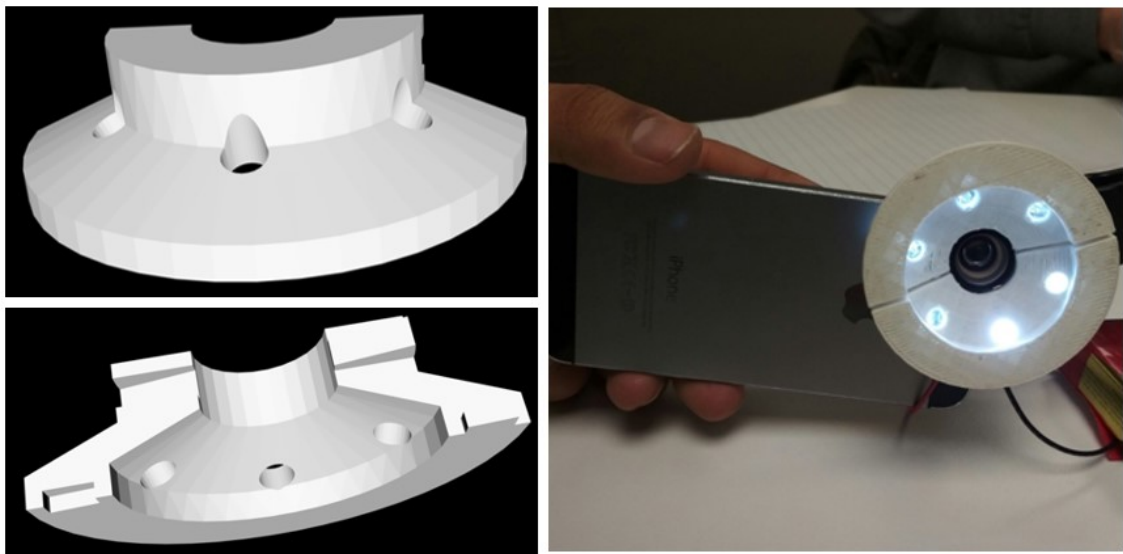
	Camera	Price	Zoom	Resolution	Aperture
D	Fuji Finepix S2995	103e*	18 x	14Mp	f3.1(w)-f5.6(t)
S	Xiaomi Mi 4+Black Eye Macro Lens	N/A+20e	20 x	13Mp	f1.8

\*D stands for digital camera, which NASA used. S stands for smartphone camera.

As the digital soil image was taken with the close distance, the external micro lens dome with 6 LED lights, which can be attached around external macro lens, was designed on the *AutoCad* (Picture 3). It was printed with the 3D printer at TAMK. Dried soil samples were placed on the paper grid (7 mm x 7 mm), which indicated size in the image, and under the dome with lights, which illuminated grain.



PICTURE 2. Black Eye Macro 20X (<https://www.verkko-kauppa.com/fi/search?query=black+eye>).



PICTURE 3. A Prototype of Macrolens Dome in AutoCad (left top and bottom) and an External Micro Lens Dome with LED Lights (Right) (Duerrenberger 2017).

Well-mixed soil samples were placed under the dome on 7 mm x 7 mm paper grid. The soil images were captured by smartphone camera, and they were saved as *jpg* files.

### 3.4.2 With Microscope

A microscope (Olympus CX 41 J), which has better image resolution than the smartphone camera, was used at TAMK laboratory. Another image was derived from the microscope for the comparison of the image result.

Well-mixed soil samples were placed on the microscope slide, and image files were saved as *jpg* file in the microscope.

## 3.5 Image Analysis

The grain particle distribution was calculated by the use of *imageJ* software in each soil sample image. *ImageJ* was open source image processing software, which was developed by the National Institutes of Health (NIH) in the United States (Figure 7). The software was available in the following web site: <https://imagej.nih.gov/ij/download.html>

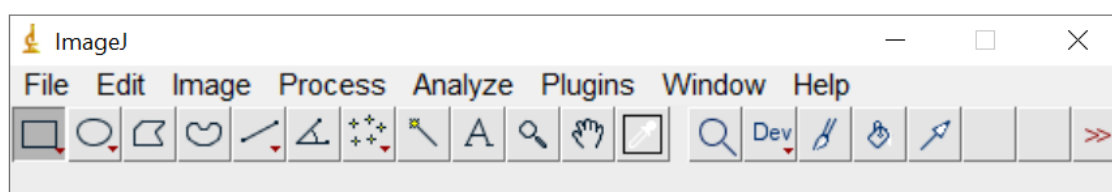

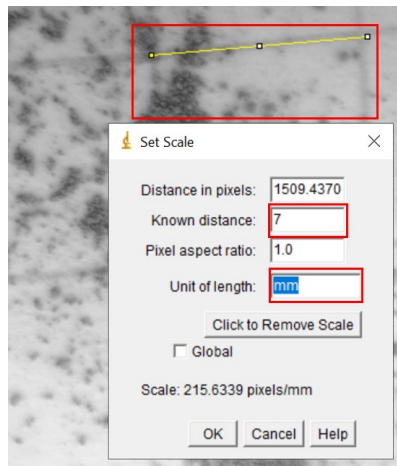


FIGURE 7. Image of *ImageJ*


<Procedures in *ImageJ* (SMS TechEdu, 2017)>

1. *File* > *Open* the soil image.
2. *Image* > *8 bit*.

3. Calibration in the image. Draw the straight line was drawn by  on the known distance of the image.
4. *Analyze* > *Set Scale*.



PICTURE 4. Image Calibration in *ImageJ*.

5.  Select image area, which needs to be analyzed and *Image > Duplicate*.
6. *Flatten image > Reveal details* in the image.
7. *Image > Adjust > Threshold*: Change color of particles or background. This helps *ImageJ* to identify particles and area, which wants to be calculated.
8. *Analyze particles*.
9. *Download CSV* file.

As *imageJ* has unique algorithm to process images and enhance the shape of particle such as *smooth*, *sharpen*, *find edges*, and *enhance contrast* under process menu, the system can identify grain particle in the image (NIH, 2012). A different image such as dark image and different colors and sizes has different method to process image. The procedure in *imageJ* above cannot be equally applied to all images.

The result was exported to csv file, and the file contains five columns such as the row number, area, mean, min, and max. After the data was imported from the csv to *excel*, the diameter was calculated from the area as the following equation in *excel*.

$$\text{Diameter} = \text{SQRT}(\text{Area}/\pi) * 2 \quad (1)$$

A histogram and pie chart were manually created from the diameters on the excel because the amount of contents in each sample was more visible than in the raw data. Before histogram is made, the particle frequency distribution table need to be created from the diameters (Table 3). The soil type is categorized by the Wentworth's soil classification. The following equation 2-5 are used in the table 3.

$$\text{Clay} \leq 3.90 \mu\text{m} \quad (2)$$

$$3.90 \mu\text{m} < \text{Silt} \leq 63.00 \mu\text{m} \quad (3)$$

$$63.00 \mu\text{m} < \text{Sand} \leq 2000.00 \mu\text{m} \quad (4)$$

$$\text{Other} > 2000.00 \mu\text{m} \quad (5)$$

In *EXCEL*, four cells in frequency column are selected, and the following *frequency* formula is inserted (Equation 6). Data array means a list of diameters in this case, and bin array means bin column in Table 3. Finally, *ctrl-shift-return* keys are pressed at the same time when *frequency* function is confirmed. As a result, the number of data, which is applied to the condition in description column, is displayed.

$$\{=frequency(\text{data array}; \text{bin array})\} \quad (6)$$

TABLE 4. The Sample of Frequency Distribution Table (Saito, 2020).

Type	Bin	Frequency	Description ( $\mu\text{m}$ )
Clay	3,90	0	$\leq 3,90$
Silt	63,00	0	$3,90 < x \leq 63,00$
Sand	2000,00	0	$63,00 < x \leq 2000,00$
Other		0	$> 2000,00$

The histogram can be created from frequency data in Table 4. The histogram showed the frequency of grain particles on Y-axis, and sizes of grain particles on X-axis. As a result, histograms of smartphone data were compared with those of the microscope data. Finally, based on Wentworth's Soil Classification (Table 1) and expected clay content (Table 2), the types of soil in containers were also identified from the result in pie chart.

### 3.6 The UX Design Tool of Mobile App

The tool of designing mobile app was Mockplus, which is one of the most popular tool for mobile app designers and developers. The development tool was downloaded from <https://www.mockplus.com/download/mockplus-rp>. When the tool was first started, email address and password needed to be registered. The following screen image was login screen of Mockplus development tool (Figure 8).

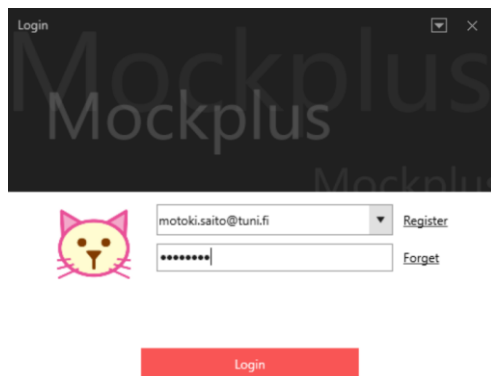


FIGURE 8. Mockplus Development Tool Login Image.

The following screen image is from Mockplus (Figure 9). UX design was created without coding a programming language.

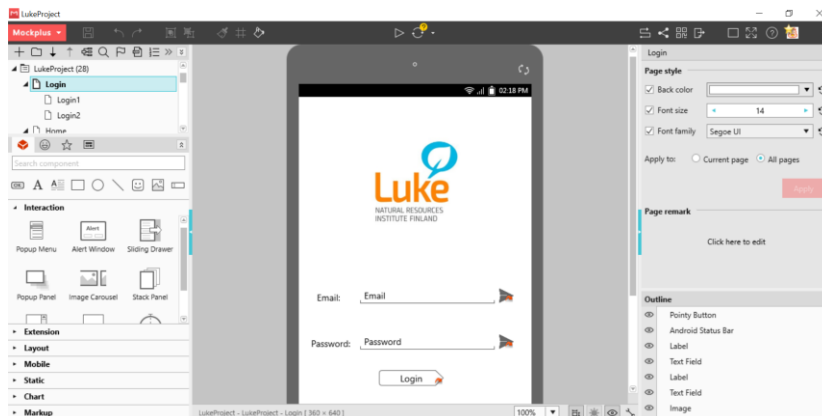


FIGURE 9. Mockplus UX Design Tool Image.

## 4 RESULTS

There were series of problems when the project was progressing. Many important events such as taking soil images, arranging laboratory schedule, studying *imageJ*, image analysis, and documentation were occurred in the last three weeks (Table 5). Until the week 46, the direction of project remained undecided, but the last day of project was fixed. Because the project schedule was tight, enough clear and fine soil images were not taken. Moreover, there were not enough training period and skills to take microscopic images.

TABLE 5. Project Schedule in 2017.

No	Week	Date	PDCA	Key Events
1	40	Oct 1-7	Plan	First Meeting with LUKE
2	41	Oct 8-14	Plan	
	42	Oct 15-21	Autumn Holiday	
3	43	Oct 22-28	Plan	Field Trip to Forest
4	44	Oct 29-Nov4	Do	Purchasing camera lens, Reviewing image analysis
5	45	Nov 5-11	Do	Designing smartphone camera stand
6	46	Nov 12-18	Do/Check	Planning Test, Designing System Concept of Mobile App
7	47	Nov 19-25	Do/Check	Test Sample Arrived, Preparation of test samples (Dry), UX Design of Mobile App
8	48	Nov 26-Dec 2	Check	Microscope laboratory session, ImageJ system test
9	49	Dec 3- Dec 9	Check	Smartphone image lab, Processing data in imageJ, Analyzing result
10	50	Dec 10-16	Action	Documentation, Presentation

In the end, only fine images from the sample 1, 4, and 7 were ready for the further image analysis because of the limitation of time schedule and skill (Table 6).

TABLE 6. Soil Particle Images Prepared.

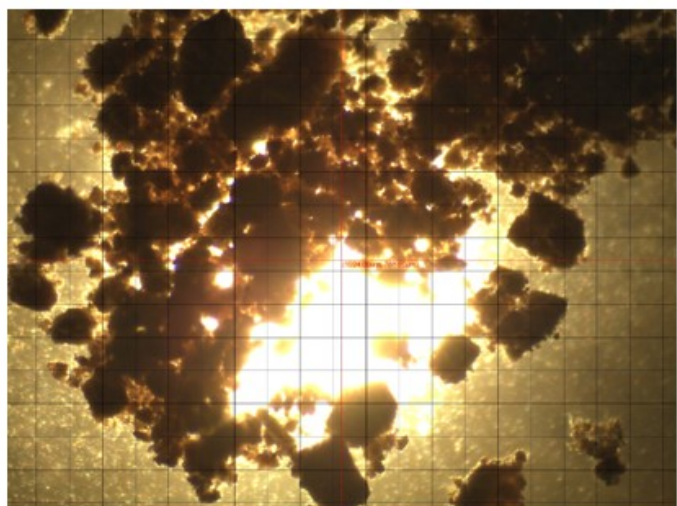
No	Sample	Conditions		Images *	
		Clay	Fine Fraction (Clay + Silt) < 0.063 mm	Smartphone	Microscope
1	Clay	> 30 %	> 50 %	○	○
2	Silt clay (Fine silt)	10 % < x < 30 %	20 % < x < 50 %	○	✕
3	Silt clay (Coarse silt) / Sandy clay (Fine sand)	10 % < x < 30 %	20 % < x < 50 %	✕	✕
4	Low-organic clay	> 30 %	> 50 %	○	○
5	Fine silt	10 % < x < 30 %	20 % < x < 50 %	✕	✕
6	Coarse silt	10 % < x < 30 %	20 % < x < 50 %	✕	✕
7	Fine sand	< 10%	< 20 %	○	○
8	Fine sand	< 10%	< 20 %	✕	✕
9	Moraine / till	0	0	✕	✕

\* x is not available, ○ is available.

## 4.1 Soil Sample Pictures

### 4.1.1 Sample 1: Clay

A clay image by use of smartphone is at left below, and that by use of microscope is at right below (Picture 5). It is important that both samples' images show the real size for running *calibration* in *imageJ*. The grain on smartphone's image was on 7 mm by 7 mm grid, and the grain on microscope's image was on 1024  $\mu\text{m}$  by 768  $\mu\text{m}$  in picture size, which is displayed in the middle of picture (Picture 5 right). *ImageJ* calculated the number of grains, and measured area of each grain after the image was manually sharpened, and particles were identified.

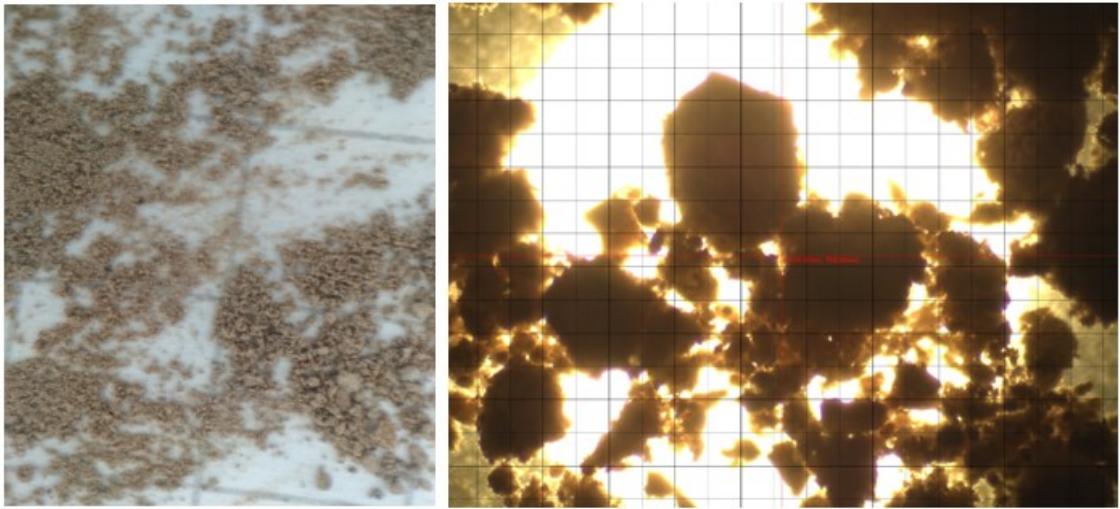




PICTURE 5. Sample 1 Clay: The grain image from smartphone at left (Sharma 2017) and the grain image from microscope at right (Saito 2017).

#### 4.1.2 Sample 4: Low-Organic Clay

A low-organic clay image by use of smartphone is at left below, and that by use of microscope is at right below (Picture 6). Like the clay sample above, both images show the real size for running *calibration* in *imageJ*. The grain on smartphone's image was on 7 mm by 7 mm grid, and the grain on microscope's image was on 1024  $\mu\text{m}$  by 768  $\mu\text{m}$  in picture size.

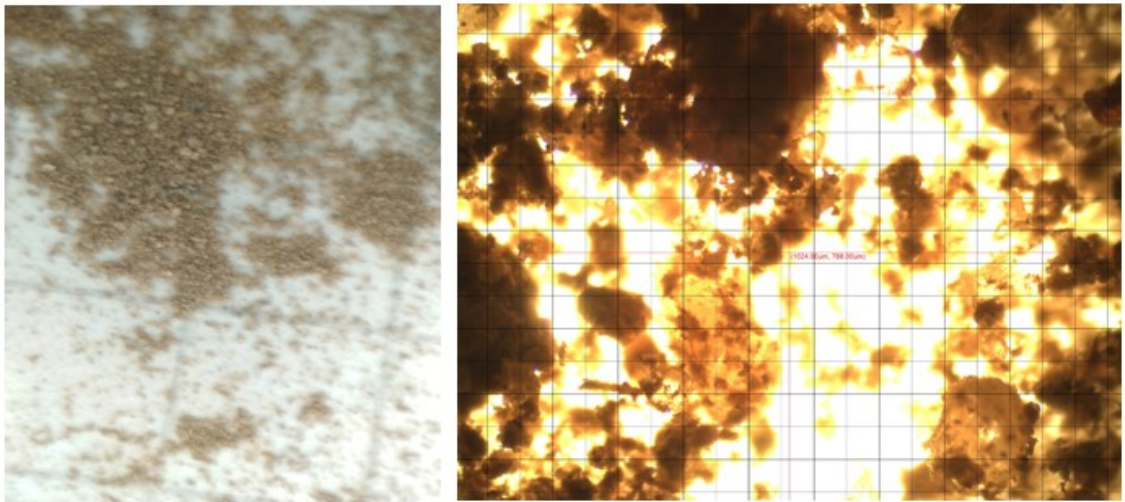


PICTURE 6. Sample 4 Low-Organic Clay: the grain image from smartphone at left (Sharma 2017) and the grain image from microscope at right (Saito 2017).

#### 4.1.3 Sample 7: Fine Sand

A fine sand image with smartphone is at left below, and that with microscope is at right below (Picture 7). both images show the real size for running *calibration* in *imageJ*. The grain on smartphone's image was on 7 mm by 7 mm grid, and the grain on microscope's image was on 1024  $\mu\text{m}$  by 768  $\mu\text{m}$  in picture size.





PICTURE 7. Sample 7 Fine Sand: The grain image from smartphone at left (Sharma 2017) and the grain image from microscope at right (Saito 2017).

## 4.2 Analysis

The result is summarized in the Table 7. *Smart* in the header means an image from smartphone, and *micro* means an image from microscope. Clay, silt and sand are categorized based on the particle size from Table 1.

TABLE 7. Soil Particle Calculation Result in Each Sample.

Sample	1. Clay		4. Low-organic clay		7. Fine sand	
Soil Type	Smart	Micro	Smart	Micro	Smart	Micro
Clay (%)	0	34,6	0	27,2	0	17,7
Silt (%)	96,7	60,4	97,7	68,5	93	78,2
Sand (%)	3,3	5	2,3	4,3	7	4
Total (%)	100	100	100	100	100	100

Here is a table, which is combined and summarized two tables, which are Table 6 and 7, into one (Table 8). *Smart* means particle images from smartphone camera, and *micro* means particle images from microscope.

TABLE 8. Summarized Conditions and Results.

No	Sample	LUKE Condition 1	Result		LUKE Condition 2	Result	
		Clay	Smart	Micro	Fine Fraction (Clay + Silt) < 0.063 mm	Smart	Micro
1	Clay	> 30 %	x	o	> 50 %	o	o
4	Low-organic clay	> 30 %	x	Δ	> 50 %	o	o
7	Fine sand	< 10%	o	x	< 20 %	x	x

x: not achieved target, Δ: Slightly lower than the target, o: achieved target.

#### 4.2.1 Particle Images from Smartphone Camera

From the *ImageJ*, it was not possible to recognize clay particle at all from smartphone image although more than 30 % of particles should be clay in both the sample 1 (clay) and 4 (low-organic clay) (Table 7). In the first condition, the result of image analysis was incorrect (Table 8). But one of conditions was satisfied that fine fraction (clay + silt) was more than 50 % in both the sample 1 and 4 (Table 6). As a result, it was correct in the second condition (Table 8).

According to LUKE's instruction (Table 7), clay should be less than 10 % in the sample 7 (fine sand). The result was zero (Table 7). In this case of sample 7, it was correct in the first condition (Table 8). The total percentage of clay and silt was 93% although it should be less than 20 % in total. As a result, it was incorrect in the second condition (Table 8).

#### 4.2.2 Particle Images from Microscope

More than 30 % clay particle was observed in the sample 1 by use of microscope. The total of clay and silt was 95 %. According to LUKE's instruction, there was more than 50 % in the sample 1 (clay). As a result, it was correct in the first and second condition (Table 8).

In the sample 4 (low-organic clay), clay should be more than 30 %, but the actual data was 27 %. As a result, it was almost correct in the first condition. Therefore, the Table 6 shows triangle ( $\Delta$ ) in this case. The total of clay and silt were more than 50 %. The total of clay and silt was 95.7 %. As a result, it was correct in the second condition (Table 8).

In the sample 7 (fine sand), clay was observed as more than 10 %, and the total of clay and silt was 96 %, which should be less than 20 %. It was incorrect in the first and second condition (Table 8).

#### 4.2.3 Histogram and Pie Chart

X-axis is bin in  $\mu\text{m}$  and Y-axis is grain particle frequency in the following histograms (Figure 10-12). The first bin represents the number of clay particle less than  $3.90 \mu\text{m}$ , and the second bin represents the number of silt particle, which has  $3.9 \mu\text{m} < x \leq 63.00 \mu\text{m}$ . The third bin represents the number of sand particle, which has  $63.00 \mu\text{m} < x \leq 2000.00 \mu\text{m}$ , and the last bin represents the number of other particle, which is bigger than  $2000.00 \mu\text{m}$ . Those soil classifications are based on the simplified Wentworth's theory in Table 1.

Those histograms clearly shows that the *imageJ* was not able to recognize clay particle in all of smartphone images, but did in the images from microscope. The most of particle, which was observed by the *imageJ*, was silt in all images.

In the clay sample, clay particle was not identified in the image from smartphone, and the most of particle was identified as silt. On the other hand, clay and silt were identified by *imageJ* in the image from microscope, but the clay was not major content. (Figure 10). The result indicates that the smartphone camera with the external macro lens was not able to capture the object, which was smaller than  $3.90 \mu\text{m}$ , the sample may not have been well-mixed, or/and the area in the image did not have well-mixed sample.

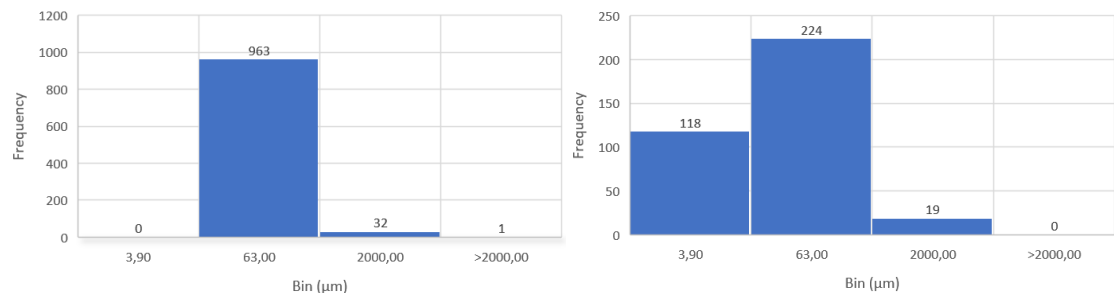


FIGURE 10. Sample 1: Smartphone Clay Particle Distribution (Left) and Microscope Clay Particle Distribution (Right).

In low-organic clay sample, clay particle was not also identified at all in the image from smartphone, but most of particle was silt and little sand (Figure 11). On the other hand, clay and silt were identified in the image from microscope, and small amount of sand, too. The result indicates that the specification of smartphone camera and that of external macro lens could not capture the object, which was

smaller than 3.9  $\mu\text{m}$ , the selected portion of sample may not have been well mixed, or/and selected area in the *image* did not have well-mixed sample.

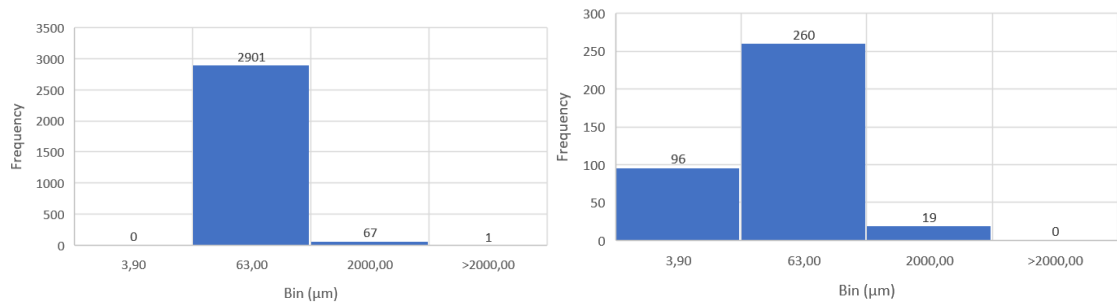


FIGURE 11. Sample 4: Smartphone Low-Organic Clay Particle Distribution (Left) and Microscope Low-Organic Clay Particle Distribution (Right).

In the fine sand sample, sand particle was not able to be identified by *imageJ* in both images although sand particle was the biggest among all (Figure 12). The possible reasons are that samples were not mixed well, and/or much sand was not included in the selected area of image.

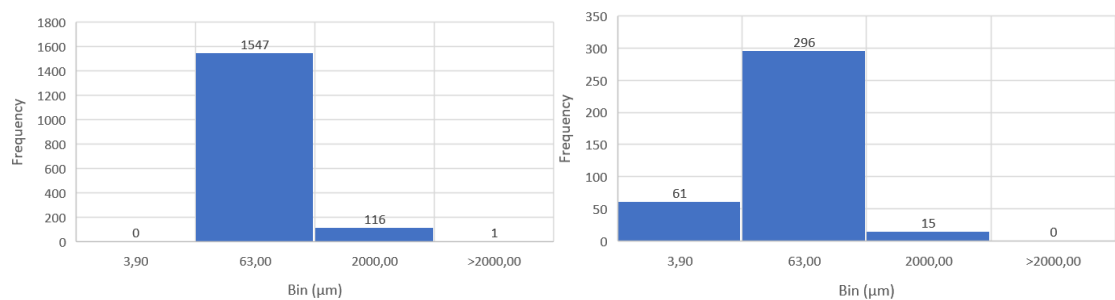


FIGURE 12. Sample 7: Smartphone Fine Sand Particle Distribution (Left) and Microscope Fine Sand Particle Distribution (Right).

Here in Figure 13-15 are pie charts, which show the percentage of different grain particle contained in each sample, based on histograms above. Four types of soil such as clay, silt, sand and other are also categorized by use of simplified Wentworth's Soil Classification in Table 1 and by use of result in Table 6 (Figure 13-15).

The smartphone camera was not able to capture clay particle images in all samples, and *imageJ* was not able to identify clay particle in the smartphone images.

On the other hand, *imageJ* recognized clay particle in the image from microscope. The result can be more visible in the pie charts.

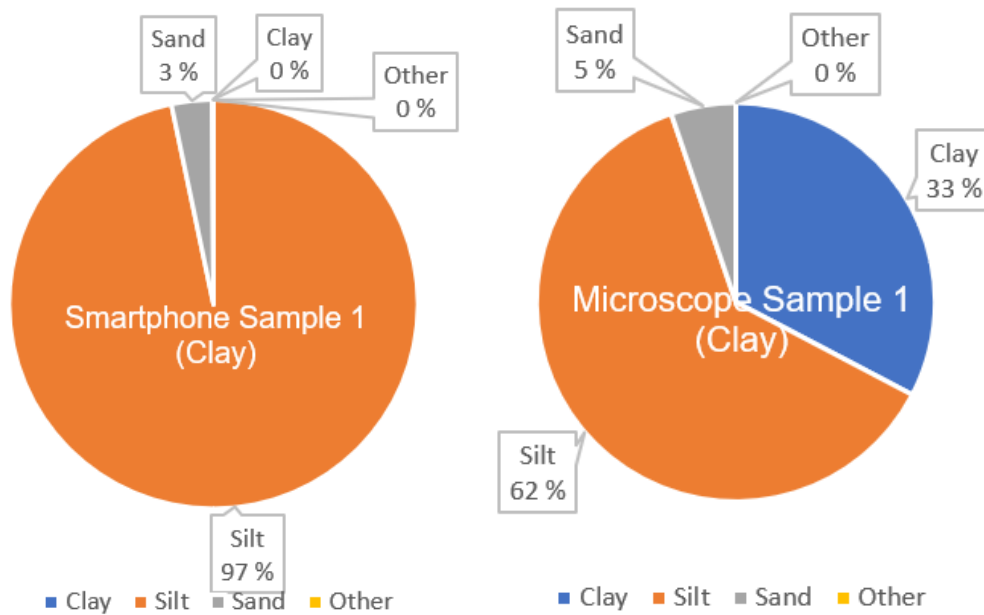


FIGURE 13. Sample 1 (Clay): The number of grain particle in selected area of smartphone image (Left) and that in selected area of microscope image (Right).

In the microscope image, the data was almost correct according to LUKE's two conditions (the clay content was slightly less than requirement.), but in the smartphone image, more clay should be contained (Figure 14). The possible reasons of no clay in the smartphone image are that the model of smartphone camera with external macro lens was not able capture the clay particle, or/and the sample may not have been mixed well in the image area.

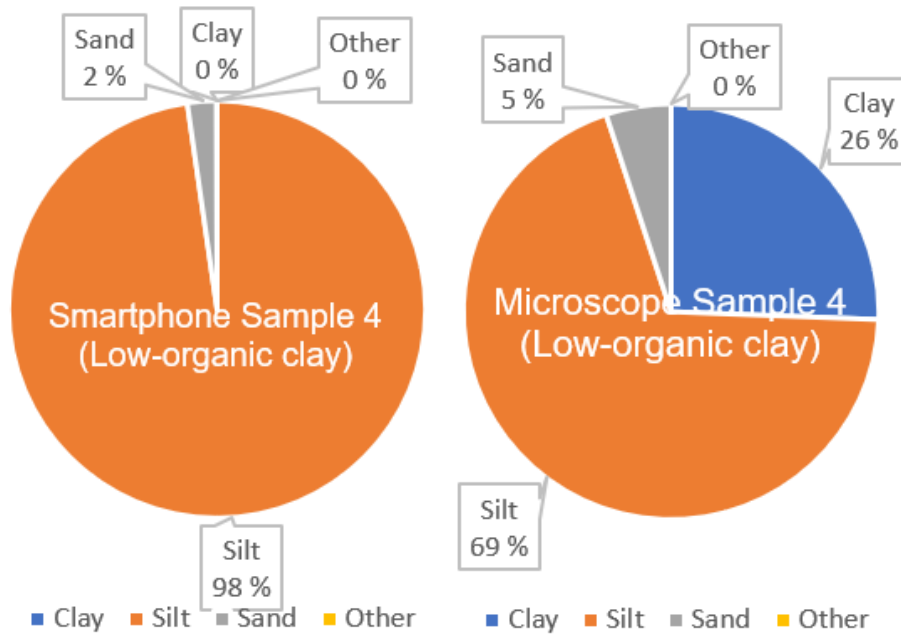


FIGURE 14. Sample 4 (Low-Organic Clay): The number of grain particle in selected area of smartphone image (Left) and that in selected area of microscope image (Right).

In sample 7 (fine sand), the sand particle is not major content in both images but silt. The sand particle is bigger than other two grains, therefore, it should be easier to be observed, but not in this case. There is possible reason that sand is not main contents. Samples may not have been mixed well in the image area. As a result, there were no sand in selected image area.

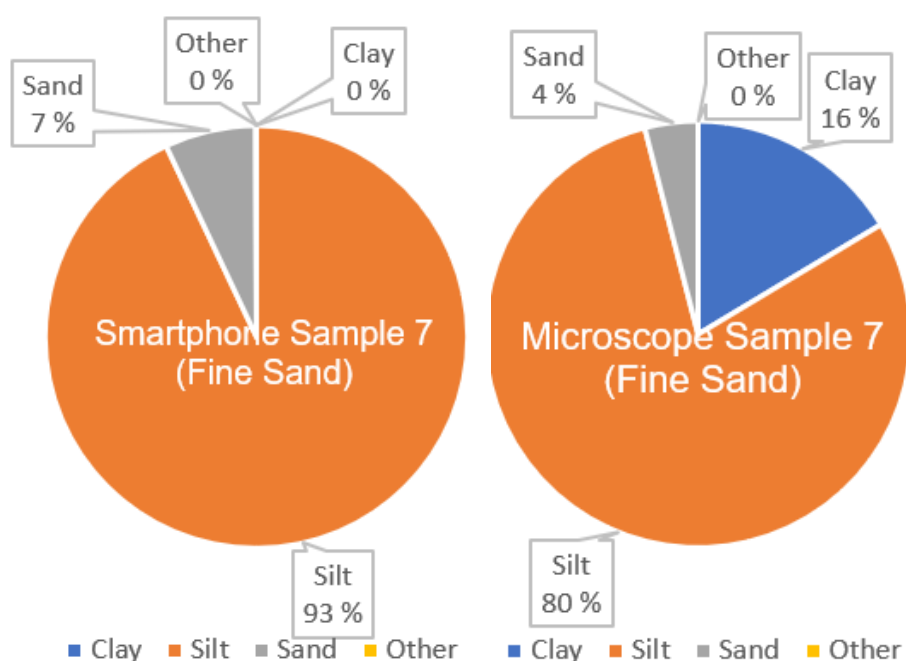


FIGURE 15. Sample 7 (Fine Sand): The number of grain particle in selected area of smartphone image (Left) and that in selected area of microscope image (Right).

### 4.3 The UX Design of Forest Soil Analyzer

The prototype of forest soil analyser was designed based on the five requirements, which were 1. Capturing soil images, 2. Analyzing soil images, 3 Viewing analysed results and history, 4. Simple and easy operations, 5. Data security.

#### 4.3.1 Basic Functions

Main functions are New, which is to register new data, and History, which is to view analysed data or processing data (Figure 16). Administrator function is only for an administrator who will register end users. More details are explained in the Data Securities section.

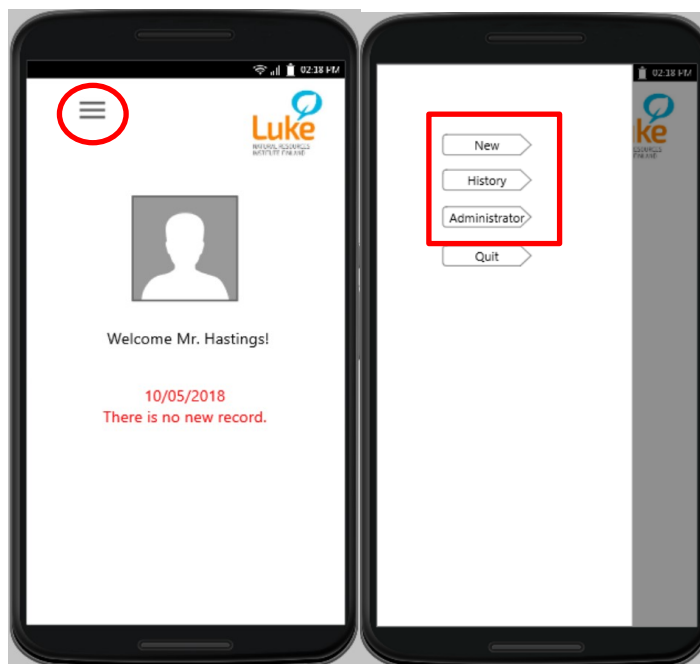


FIGURE 16. Main Functions (Saito, 2020).

When a user clicks a New button above, a user can register the new soil sample data (Figure 17). There are three main categories such as *Basic*, *Map*, and *Image*. In the *Basic*, a user input, date, a person who is in charge of sample, and descriptions such as weather. In the *Map*, a user input area, plot, and selecting

location from a map. In the Image, a user selects the sample depth, and images from a smartphone.

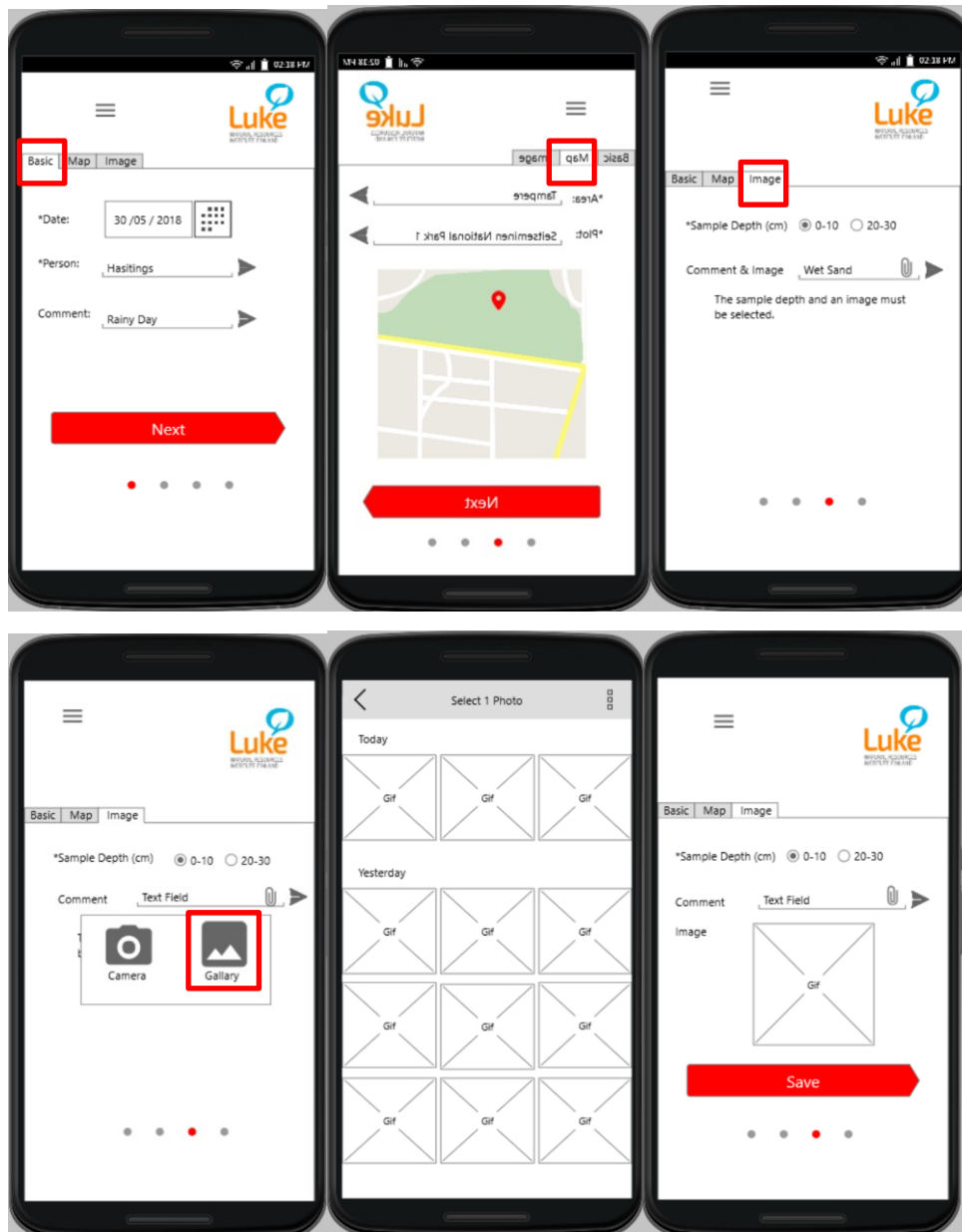


FIGURE 17. Registering New Soil Sample Data. Clockwise, from top left, *Basic*, *Map*, *Image* main, the screen image when a user clicks clip in the *Image*, images from gallery in the smartphone, and the screen image after a user selects an image (Saito, 2020).

The following screen images are completing a process of new sample image registration (Figure 18). After a user selects an image, he can review the summary



of new sample data. If the data is correct, he presses Register button. It makes the registration complete.

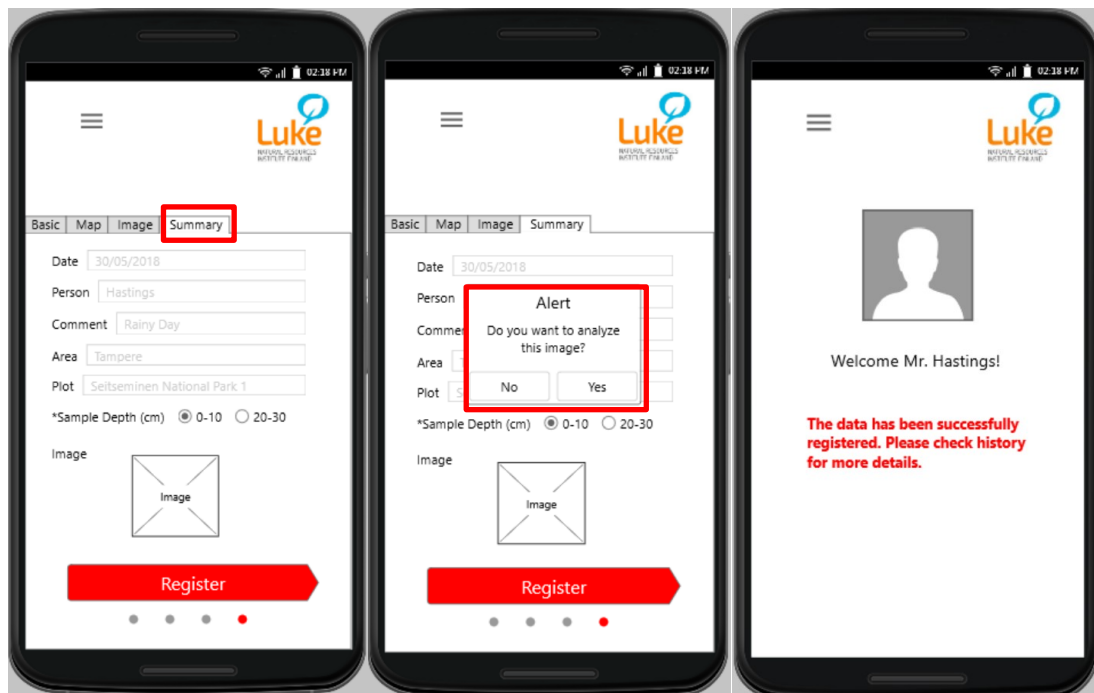


FIGURE 18. Viewing new sample data summary and completing the registration of sample data (Saito, 2020).

The following screen images are from *History* function. There are three categories such as *Uploaded*, *Analyzed* and *Failed* (Figure 19). In the *Uploaded*, a user can see the sample data, which is just registered. In the *Analyzed*, a user can see the sample data, which is already successfully analyzed. In the *Failed*, a user can see the sample data, which was failed to be analyzed for some reason such as an unclear image (Figure 19). In all the categories, a person in charge of the sample, location, date, checkbox for data download columns can be seen.

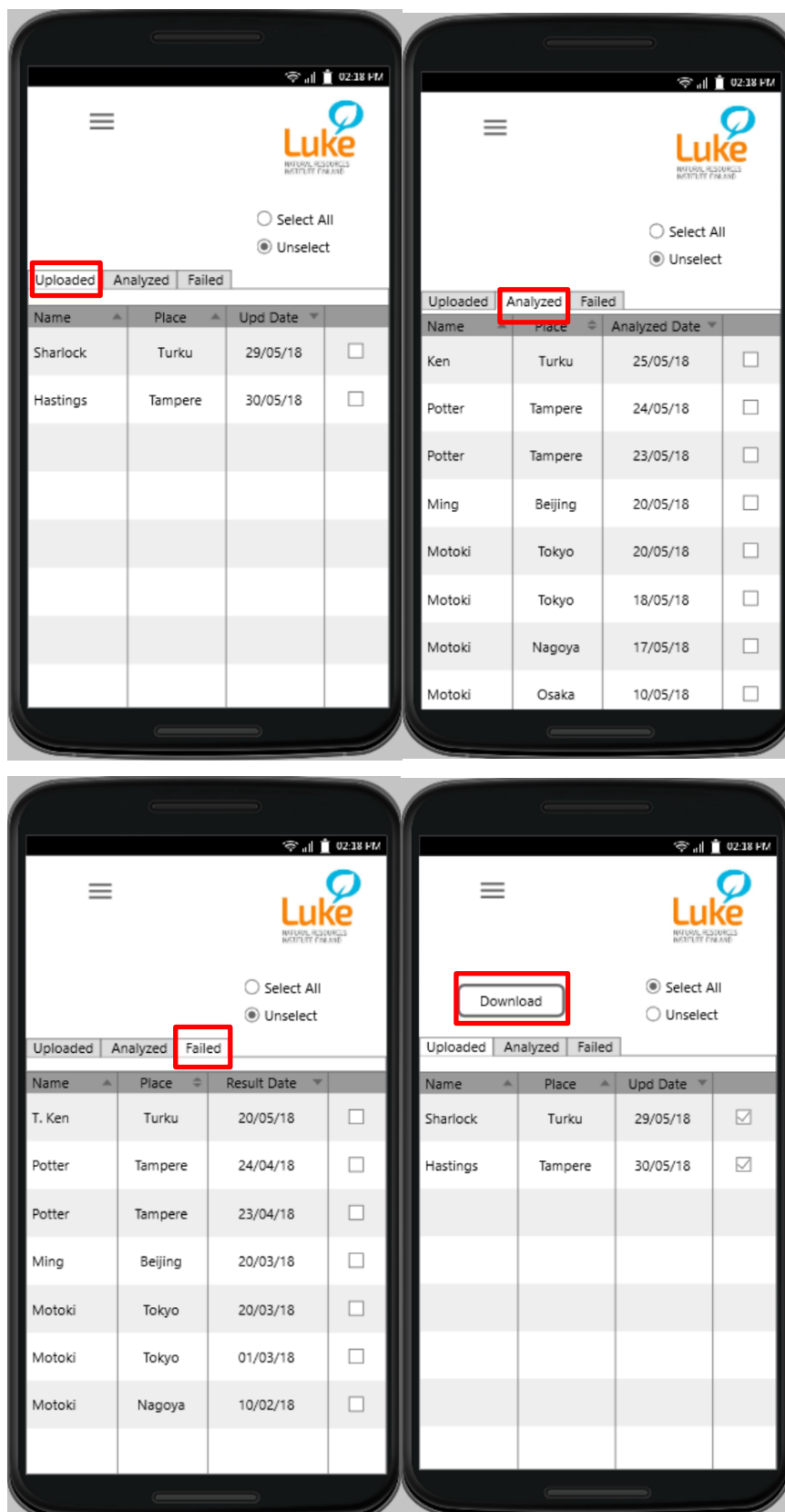


FIGURE 19. *History* function images. Clockwise, from the top left, *Uploaded*, *Analyzed*, *Failed* and the last image shows data download button (Saito, 2020).

The data is categorized as registered, analysed, and failed. Registered means that sample data is just registered and it is waiting to being analysed, Analyzed

means that the sample data is successfully analysed. Failed status means that the sample data cannot be analysed. A user needs to register the data again (Figure 20).



FIGURE 20. Data Categories in the *History* (Saito, 2020).

#### 4.3.2 Data Securities

The following images are login screen in the mobile app (Figure 21). The app cannot be used without registering users by an administrator in this case, LUKE. It provides an initial level of security to the system.

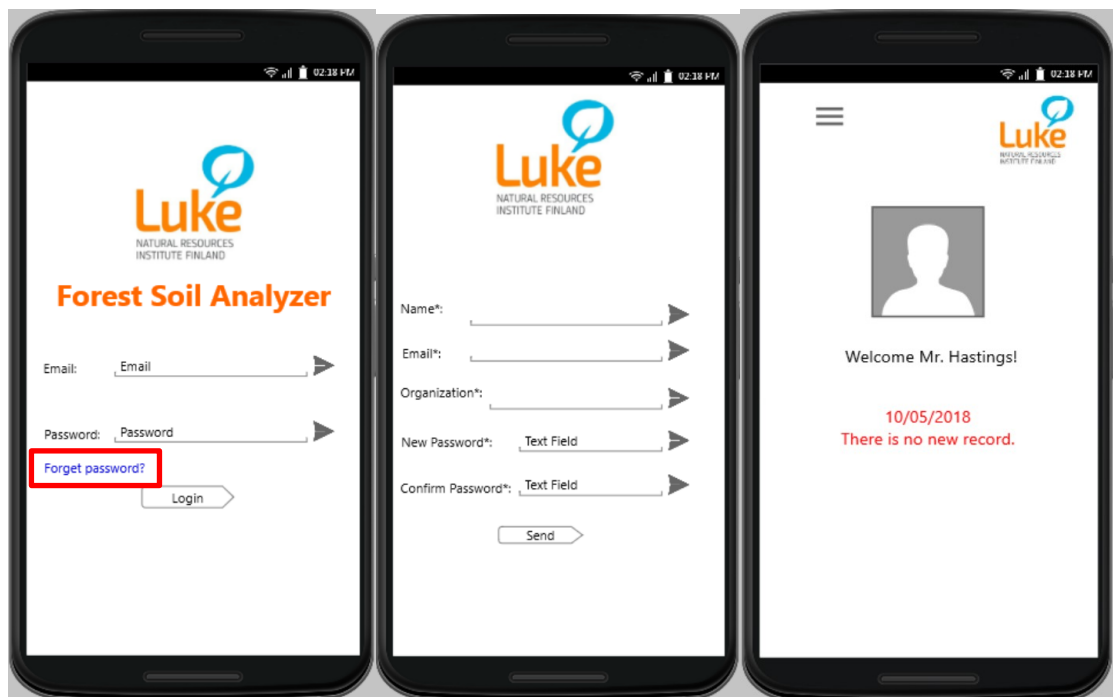


FIGURE 21. Login Screen Image (Saito, 2020).

Here is a user request flow (Figure 22). When a user clicks Forget password? link in the login screen above, he sends information such as name, email, organization, and new password to an administrator. The request can be rejected, but the following flow mentions only approval.

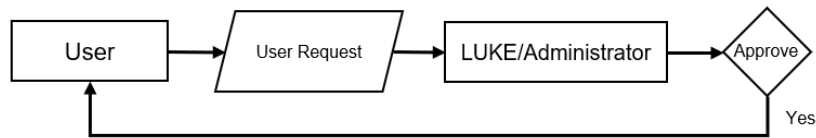


FIGURE 22 User Request Flow (Saito, 2020).

The following images are administrator screens in the mobile app (Figure 23). It gives only administrator access to this function. An administrator can approve a user request and promote an end user to becoming an administrator whose right is adding by filling with a tick in a checkbox next to email address below.

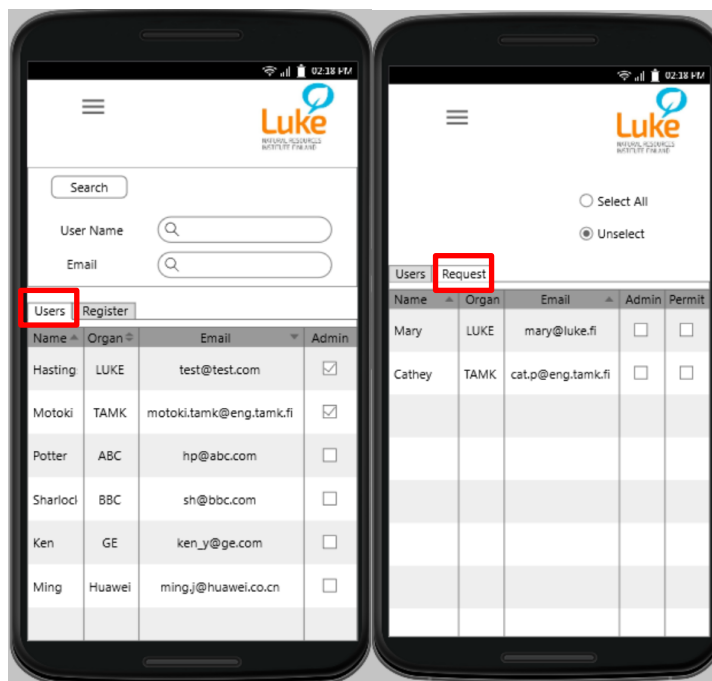


FIGURE 23. Administrator Screen Image (Saito, 2020).

## 5 DISCUSSION

This thesis took on challenges of gaining the new knowledge of image analysis from various soil samples. The samples were provided with two conditions: the first condition was estimated clay contents in each sample, and the second condition was estimated clay and silt contents in each sample. As a result, in the first condition, the smartphone camera could only recognize silt, not clay, which was the smallest grain particle in all samples. The microscope recognized clay accordingly in the sample 1 (clay) and 4 (low-organic clay), but more than instructed clay amount (less than 10 %) in the sample 7 (fine sand) was observed. Moreover, as *imageJ* identified the most of particle as silt in all images, the second condition was achieved in the sample 1 and 4, but 7 (Table 8).

### 5.1 What do those results indicate?

Results suggest instrumental/physical issues. The *imageJ* was unable to recognize clay in the images from smartphone camera at all although clay was recognized from the microscope image by *imageJ*. It suggests that the images could not be focused well with the external macro lens, or/and the performance of smartphone camera did not respond to microscopic images well. Due to limited budget and short project period, only smartphone camera was used. Therefore, multiple different spec of smartphone cameras should be tested.

*ImageJ* has many parameters, which are unused. If different parameters were used, the result may be different such as use of different image enhancement. Therefore, the further study of *imageJ* algorithm guide us to having more accurate result.

To make results better, I would suggest that all procedures would be standardized. The method of mixing samples would be, for example, using a mixer for 10 seconds and 20 seconds. The sample size in the image would be, for example, capturing 10 g of samples with different angles and different lighting. The sample would be spread on the paper grid or stage in the microscope, for example, a

paper grid and the stage in the microscope would be completely covered by samples.

Besides, the number of samples was not sufficient. More sand could have been observed in the sample 7 (fine sand) although *ImageJ* did not detect much sand (less than 4 %) from both smartphone's and microscope's images. The fine sand sample should contain more sand; however, it cannot be judged by only using sample and image. At least more than two similar types of soil should be used, and multiple images in the sample need to be captured for checking accuracy.

On top of the instrumental/physical issues, there are several logical ones. One of them was too short project schedule for a huge task. Project members are full-time students in two different universities of TAMK and TUT. Ten weeks were given to us, and the detail test plan was not fixed by the week 6 (Table 5). The final test plan was created by Saito. Many tasks such as obtaining soil samples, arranging laboratory work, studying *imageJ*, analyzing images, and documentation were arranged in a rush. As a result, images of only three samples were captured and analyzed. The project schedule should be longer and should be considered as a part of studies. Ideally, project members should wholly commit to this project without any other engagements in one semester (about three months). The first month is a planning phase, and the second month is for preparing samples and capturing images, while the third month is for analyzing images and documentation. In addition, technical support of capturing microscopic images with camera would be also needed.

Likewise, a more accurate, third checking process such as expecting result from laboratory or trial of sieving method in the laboratory should be added in the test plan for comparing results. The accuracy of image analysis could then be more objectively proved.

Designing the mobile app had second priority. Unless the result of image analysis evaluated well, the development of the app could not be proceeded. More people carry a smartphone in Finland, and the quality of smartphone camera is also improving every year. The development of mobile app is an inevitable result for

observing microscopic images. That's why the project members chose the smartphone camera and mobile app as a mobile soil image analyzer.

## 5.2 Answering Research Questions

I proposed three research questions in chapter 2.1:

Q1. Can grain particle such as clay, silt and sand be identified by use of the images?

Q2. What standardized processes can be gone through the image analysis of grain particle?

Q3. Can we find out the minimum specification of smartphone camera to capture grain particle?

I will now answer these questions in the paragraphs below.

A short answer to the first question is, "yes". In the microscope images, clay, silt and sand were identified by the *imageJ*, but not in the smartphone images. The smartphone camera of Xiaomi Mi4 captured silt and sand, but not clay particle. Different camera models should be tested.

Answer for the second question is that the three phases of processes such as preparing samples, capturing images, and analyzing images were precise arrangement. The first phase was mainly conducted by LUKE, and this thesis focuses on the second and third phase. The second phase was capturing images by smartphone camera and microscope. The more images are taken from different samples, the more precise the result becomes. The third phase was analyzing images by *imageJ*. There were different grain colors and size. The adjustment target of images with parameters in *imageJ* should be shown clearly. Otherwise, a user adjusts images with own different values and decision, and it causes different result in *imageJ*.

For the third questions the answer depends on what grain needs to be observed. Silt and sand particle can be monitored in Xiaomi Mi4 camera plus external macro

lens. Higher specification of camera is recommended than Xiaomi Mi4 if clay particle also needs to be observed. For more precise measurement of grain particle size, sieving method should be simultaneously used until more data is collected.

### 5.3 Image Analysis in the Future

Taking an image of clay grain particle (the smallest grain particle) with smartphone camera and analysing the image will be realized in the future, but not this time. Similarly, Mars Rovers took images of sand grain particle ( $> 0.1$  mm in diameter), which is bigger than clay, with high resolution cameras, and was able to analyze the images in *ImageJ* (Kozakiewicz 2018, 264-265). In the extra-terrestrial missions, images continue to be the main source of information. Therefore, a camera and image analysis process continue to be developed. If the process of soil image analysis is more convenient and faster than a conventional method, there may be room for market not only in the forestry, but also in mine, agriculture, and construction sector.

Finally, note that a user needs to understand all processes of soil image analysis. The system consists of many processes such as choosing a right camera, taking images with light, right angle, and focus, setting different parameters in the system, and analysing images. The result may be different depending on those processes, which a user takes, although the future system will be convenient if forest soil image analyzer is developed in smartphone.



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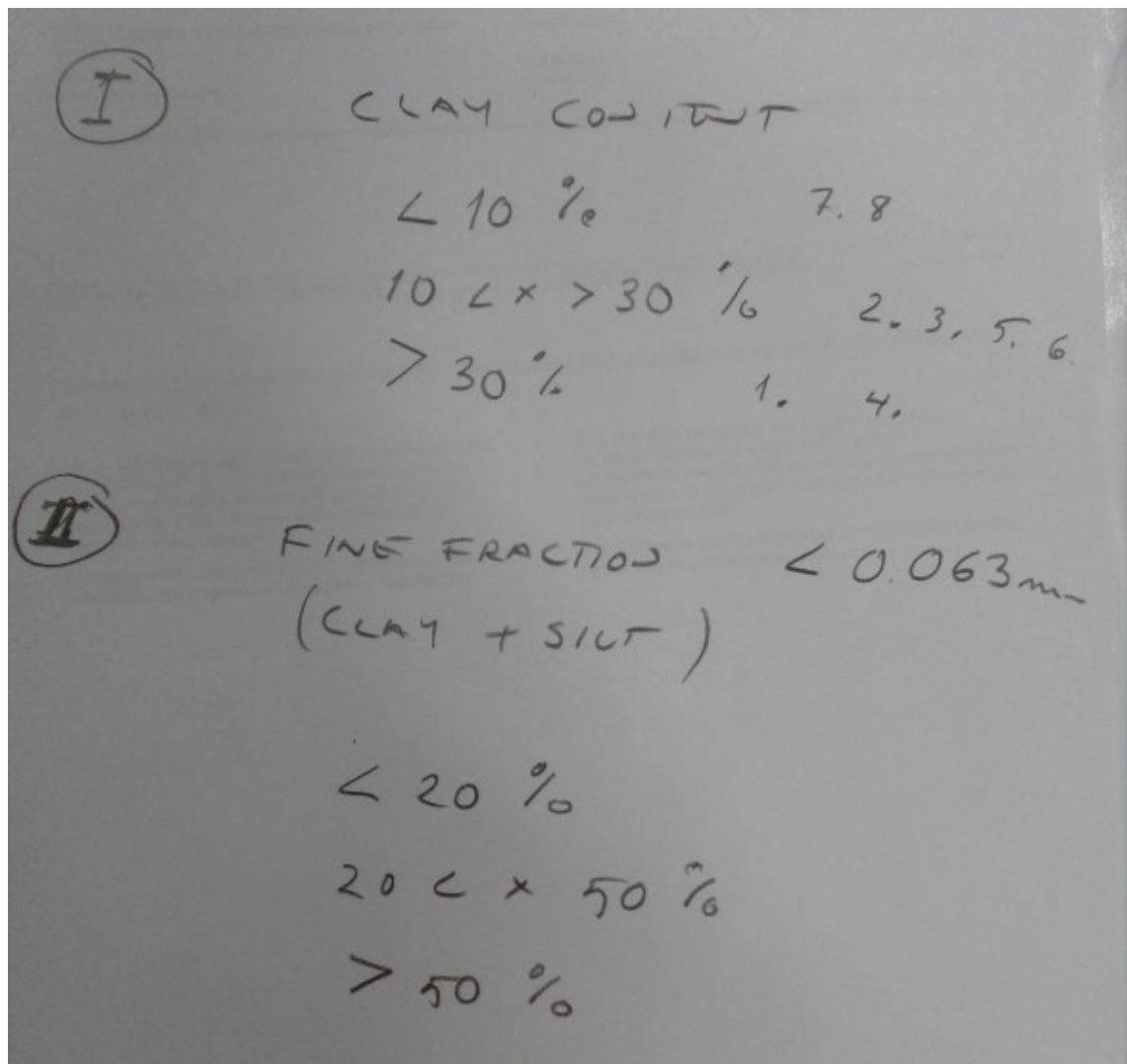
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## APPENDICES

## Appendix 1. Soil Sample Instruction by LUKE



## Appendix 2. UX Design Mind Map (Saito, 2020)

